

A History of Reverse Total Shoulder Arthroplasty

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Abstract

Background Management of the cuff-deficient arthritic shoulder has long been challenging. Early unconstrained shoulder arthroplasty systems were associated with high complication and implant failure rates. The evolution toward the modern reverse shoulder arthroplasty includes many variables of constrained shoulder arthroplasty designs.

Questions/purposes This review explores the development of reverse shoulder arthroplasty, specifically describing (1) the evolution of reverse shoulder arthroplasty designs, (2) the biomechanical variations in the evolution of this arthroplasty, and (3) the current issues relevant to reverse shoulder arthroplasty today.

Methods Using a PubMed search, the literature was explored for articles addressing reverse shoulder arthroplasty, focusing on those papers with historical context.

Results Results of the early designs were apparently poor, although they were not subjected to rigorous clinical research and usually reported only in secondary literature. We identified a trend of glenoid component failure in the early reverse designs. This trend was recognized and reported by authors as the reverse shoulder evolved.

Authors reported greater pain relief and better function in reverse shoulder arthroplasty with the fundamental change of Grammont's design (moving the center of rotation medially and distally). However, current reports suggest lingering concerns and challenges with today's designs.

Conclusions The history of reverse shoulder arthroplasty involves the designs of many forward-thinking surgeons. Many of these highly constrained systems failed, although more recent designs have demonstrated improved longevity and implant performance. Reverse shoulder arthroplasty requires ongoing study, with challenges and controversies remaining around present-day designs.

Introduction

Arthroplasty of the shoulder has offered the potential for improved function and pain relief where the native gleno-humeral articulation has been damaged by infection, arthritis, or trauma. The early history of shoulder arthroplasty has been widely reported [8, 12, 40]. Themistocles Gluck was an early pioneer of joint arthroplasty and likely designed the first shoulder arthroplasty in the late 1800s [2, 12], although he never published on the implantation of his shoulder designs in humans. Therefore, the first prosthetic shoulder arthroplasty performed has widely been ascribed to the French surgeon Jules Emile Péan in 1893 [30]. After débriding tuberculous arthritis of the shoulder in a 37-year-old baker, Péan implanted a platinum and rubber replacement. The patient reportedly had increased strength and ROM. Unfortunately, the infection recurred, requiring removal of the prosthesis 2 years later.

Arthroplasty played a limited role in the treatment of shoulder problems until in 1955 when Neer [32] reported 11 of 12 patients with proximal humerus arthroplasty (Neer

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1) for fractures with a Vitallium prosthesis were free from pain. In 1974, Neer [33] subsequently described the use of his proximal humeral arthroplasty for the treatment of glenohumeral osteoarthritis and reported the clinician-documented outcomes as “excellent” in 20 patients, “satisfactory” in 20, and “unsatisfactory” in four. Patients in this series described their results as “enthusiastic” in 27, “satisfied” in 15, and “dissatisfied” in four. A number of other series followed over the next 20 years reporting the use of hemiarthroplasty for traumatic and degenerative changes in the glenohumeral joint [22, 31, 33, 46].

Although pain relief was reliably obtained with hemiarthroplasty, Neer [33] reported variable strength and function in patients with irreparable rotator cuff tears. Superior humeral head migration was often seen postoperatively in patients who had lost the stabilizing function of the rotator cuff. Marmor [31] in 1977 reported on five patients in his series with rotator cuff tears, all exhibiting superior migration. This led him to propose total shoulder arthroplasty for some of these patients, presuming the addition of a glenoid component might stabilize the humeral head and prevent migration.

Surgeons in the 1970s recognized the difficulty inherent in the development of a satisfactory prosthesis for glenohumeral arthroplasty, acknowledging the challenges in balancing joint stability with ROM. Inman et al. [20] reported on the substantial forces across the shoulder during ROM and noted, at 90° elevation, the force against the glenoid represents 10.2 times the weight of the extremity, nearly the entire body weight. Surgeons have acknowledged the stabilizing role of the rotator cuff and noted the loss of these stabilizers may lead to additional force on the implant [9, 42, 43]. Many series also noted the poorer function of arthroplasty in patients with a deficient rotator cuff, recognizing the prime movers of the shoulder were unable to act in the absence of a stabilizing force of the rotator cuff [33, 42].

Katz et al. [21] previously published a history of reverse shoulder arthroplasty, and in this article, we seek to add to that history with a review of previous designs and a discussion of the most recent issues surrounding reverse shoulder arthroplasty. We therefore review the development of reverse shoulder arthroplasty, specifically describing (1) the evolution of reverse shoulder arthroplasty, (2) the biomechanical variations in the evolution of this arthroplasty, and (3) the current issues relevant to reverse shoulder arthroplasty today.

Search Strategy and Criteria

We performed a review of the available literature using a PubMed search with the terms “reverse,” “shoulder,” and

“arthroplasty.” This search returned 130 results, which were all submitted to an abstract review to identify articles with historical context. The references of applicable publications were also reviewed to include any reports not obtained by the PubMed search. From these sources, we identified and selected the 51 articles we include here.

Rotator Cuff and Constraint in Total Shoulder Arthroplasty

In a review of his series dating from 1973 to 1981, Neer [35, 36] acknowledged outcomes of arthroplasty were poorer when the rotator cuff was not functional. He initially explored constrained designs, believing this would obviate the need for reconstruction of the rotator cuff. Neer designed three variations of constrained total shoulders, each having a reversed glenohumeral articulation. The first, the Mark I, included an oversized ball to provide increased motion (Fig. 1) [34]. However, this enlarged ball prevented rotator cuff reattachment. The second version, the Mark II, was modified to a smaller ball to allow rotator cuff repair. Unfortunately, this led to decreased excursion and motion [21]. The third variation, the Mark III, added axial rotation to the stem (Fig. 2) in an attempt to regain motion. Dislocation and scapular fixation remained a concern with this implant [24], and Neer remained convinced rotator cuff

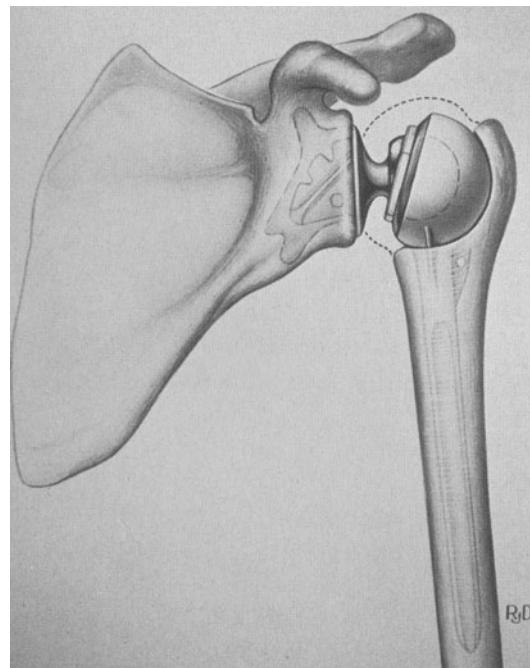


Fig. 1 Neer's Mark I design with larger spherical component allowed greater motion. Reprinted with permission from Neer CS 2nd. *Shoulder Reconstruction*. Philadelphia, PA: WB Saunders; 1990. Copyright © 1990 Elsevier.

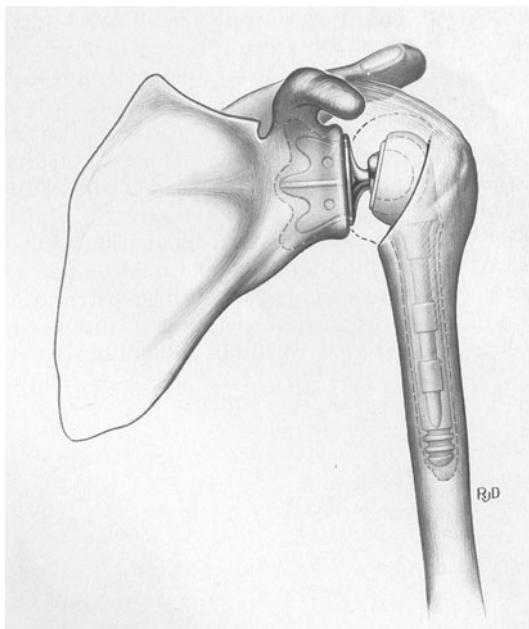


Fig. 2 Neer's Mark III system incorporated axial rotation of the prosthetic stem. Reprinted with permission from Neer CS 2nd. *Shoulder Reconstruction*. Philadelphia, PA: WB Saunders; 1990. Copyright © 1990 Elsevier.

repair, not constraint, was essential for improved shoulder function. His Mark III prosthesis was therefore abandoned, although others continued to explore the reverse shoulder concept.

Some surgeons continued to pursue fixed-fulcrum systems. In the 1970s, designs by Bickel [10, 29] (Fig. 3) and the Stanmore prosthesis by Lettin and Scales [11, 26, 27, 39] (Fig. 4) maintained the standard ball-and-socket glenohumeral articulation, although with increased constraint. The Bickel prosthesis had a small ball-shaped humeral component completely constrained within a polyethylene socket. This socket was seated within the glenoid vault and required a substantial amount of bone removal from the scapula. Complication rates were high and included loosening in 9%, fracture in 18%, and pain in 27% at 18 to 39 months postoperatively [10]. The Stanmore components snapped together after implantation and the glenoid was heavily supported by methylmethacrylate cement. Although some patients had improvement in their function and ROM, this improvement was reported as “inconsistent and disappointing” [26]. The most important complication with these designs was loosening of the glenoid components [9], leading to excessively high rates of revision.

In 1979, Kessel and Bayley [23] recognized the challenge in designing a glenoid implant within a heavily constrained system, stating “the scapular bone is unsuitable for holding a prosthesis with acrylic cement.” Others [10, 35] expressed concern over the limited bone stock in the glenoid vault and the risk for failure given the forces



Fig. 3 The Bickel shoulder prosthesis illustrates the medialized glenoid component, which required substantial bone removal for implantation. Reprinted with permission from Cofield RH. Status of total shoulder arthroplasty. *Arch Surg.* 1977;112:1088–1091. Copyright © 1977 American Medical Association. All rights reserved.



Fig. 4 The Stanmore total shoulder prosthesis maintained the standard ball-and-socket glenohumeral articulation, although with increased constraint. The components snapped together after implantation and the glenoid was heavily supported by methylmethacrylate cement. Reprinted with permission from Cofield RH. Status of total shoulder arthroplasty. *Arch Surg.* 1977;112:1088–1091. Copyright © 1977 American Medical Association. All rights reserved.

translated across such a limited area. As more studies reported loosening of glenoid components in these systems, shoulder arthroplasty modulated toward glenoid components secured without cement, relying on flanges, pegs, and screws. With the marked increase in glenoid fixation, glenoid and scapula fractures became a major concern. To reduce the risk of this catastrophic complication,

constrained prostheses were designed to dislocate at lower forces than required for scapula fracture [39]. Despite this design change, failures continued and many series reported high revision rates [37, 38].

Given the challenges of constrained shoulder arthroplasty, many began to explore a very different sort of shoulder arthroplasty. Keeping in mind the stress at the glenoid-implant interface, these new designs further explored a reverse ball-and-socket design. Proponents suggested this change would address the concerns with scapular fixation and improve patient function by relying on a major change in arthroplasty design.

Reverse Total Shoulder Arthroplasty

New total shoulder arthroplasty designs in the 1970s reversed the normal anatomy by placing the socket in the proximal humerus and the prosthetic ball on the glenoid. Proponents for this design argued this change would allow improved motion and strength without the increased risk of dislocation and loosening. A number of reverse implant systems were designed beginning in the 1970s with variable designs for scapular fixation [1, 3, 4, 6, 7, 13, 16, 17, 25, 41, 42] (Table 1). These prostheses created a foundation for reverse shoulder arthroplasty and made important contributions to our understanding of the reverse concept.

To address the issue of scapular fixation, in 1972, the Leeds shoulder included a divergent threaded peg glenoid component (Fig. 5) [41]. This design by Reeves et al. [42] demonstrated higher pullout strength than other designs in in vitro testing. This reverse system also was designed

around an instant center of rotation, which recreated the normal anatomic center.

Many designs explored unique methods of scapular fixation to address the frequent complication of glenoid loosening. Kessel's design in 1973 included a single central screw. One study reported decreased pain and some improvement in function [4]. Although this design

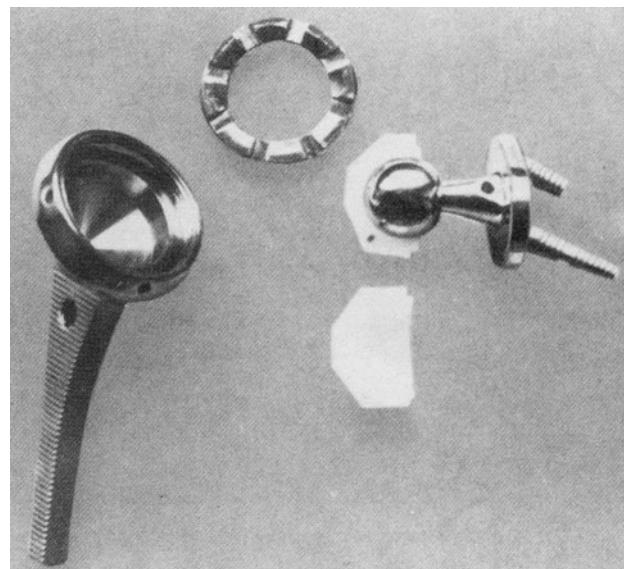


Fig. 5 The Reverse Total Shoulder System designed by Reeves et al. included a divergent threaded peg glenoid component, demonstrated higher pullout strength than other designs in vitro testing, and was designed around an instant center of rotation, which recreated the normal anatomic center. Reprinted with permission of Professional Engineering Publishing from Reeves B, Jobbins B, Dowson D, Wright V. A total shoulder endoprosthesis. *Eng Med*. 1974;1:64–67.

Table 1. Reverse shoulder arthroplasty designs

Prosthesis name/designer	Year introduced	Key design features
Leeds Shoulder/Reeves et al. [41, 42]	1972	Glenoid component with divergent threaded peg; center of rotation recreated anatomic center
Kessel [4, 6]	1973	Single central glenoid screw; center of rotation placed laterally
Kölbl and Friedebold [25]	1973	Flange bolted glenoid component to scapular spine; designed to allow dislocation at lower forces
Bayley-Walker [1]	1973	Large hydroxyapatite-coated screw; center of rotation moved medially and distally
Fenlin [14]	1975	Glenosphere enlarged to increase deltoid lever arm
Liverpool/Beddoes and Elloy [3]	1975	Glenoid component included a stem fixed into the scapular pillar to improve glenoid fixation
Buechel et al. [7]	1978	A “floating fulcrum”; glenosphere decreased in size to increase shoulder motion
Trispherical/Gristina and Webb [17]	1978	A glenosphere and a small sphere on the humerus, both articulating in a larger polyethylene cup
Grammont Version 1 [16]	1985	Center of rotation medialized but remained lateral to native glenoid surface; glenoid baseplate had a press-fit central peg
Delta III/Grammont	1991	Center of rotation further medialized to the native glenoid face; glenoid baseplate coated with hydroxyapatite to improve fixation

theoretically allowed anatomic ROM, *in vivo* study did not demonstrate an improvement in ROM [6]. A series of 17 shoulders (all with rheumatoid arthritis) followed for 87 months noted active motion was unchanged and all shoulders had radiolucent lines seen within a year [6]. With further followup of 23 prostheses, three were removed and three were revised [51].

Earlier constrained designs, particularly the Bickel prosthesis, required marked bone removal from the glenoid vault for implantation of the glenoid component. Bone loss and removal remained a concern as designs progressed. In 1973, the prosthesis designed by Kölbel and Friedebold [25] was intended for shoulder reconstruction after tumor resection. As bone loss was often seen in these cases, obtaining secure fixation was an important goal. With this in mind, Kölbel and Friedebold added a flange that bolted to the base of the scapular spine and functioned in stress transfer (Fig. 6). This prosthesis was also meant to allow dislocation at lower forces.

In 1973, the Bayley-Walker system made advancements in both design and fixation [1]. This implant was similar to the Kessel prosthesis but sought to improve the design by coating the large central screw with hydroxyapatite and increasing the screw thread diameter. In this design, the center of rotation was moved medially and distally with the specific goal of increasing the abductor muscle lever arm. These design changes were made in an attempt to achieve secure glenoid fixation without a concomitant increase in loosening. In a total of 124 Bayley-Walker shoulders, no radiolucencies were noted after 5 years [1].

As reverse shoulder arthroplasty design progressed, maximizing deltoid function became a greater focus. Fenlin [13] emphasized the importance of an enlarged ball-and-socket construct, believing a larger glenosphere would

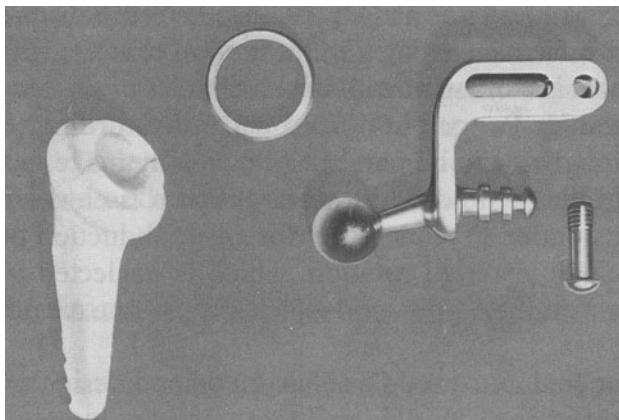


Fig. 6 Components of the shoulder prosthesis designed by Kölbel and Friedebold are shown. Reprinted with permission of Georg Thieme Verlag KG from Kölbel R, Friedebold G. Shoulder joint prosthesis [in German]. *Z Orthop Ihre Grenzgeb*. 1975;113:452–454.

increase the glenohumeral motion and increase the deltoid lever arm (Fig. 7). This fixed-fulcrum system released in 1975 was designed to allow the deltoid to compensate for the deficient rotator cuff, and this design was truly focused toward the patient with cuff tear arthropathy. Although early results were promising, long-term followup identified implant breakage, prosthesis loosening, and anterior instability [14].

The Liverpool shoulder [3] was initially designed in 1969 by Beddow and Elloy and was similar to the design of a hip prosthesis (Fig. 8). The glenoid component and stem were fixed into the scapular pillar with the polyethylene socket cemented into the proximal humerus. This design recreated the anatomic center of rotation [50]. Five-year followup was available for 16 of 19 prostheses, and although pain was relieved for 11, four patients developed loosening of the scapular component.

The design by Buechel et al. [7] in 1978 was based on a floating fulcrum, with characteristics designed to allow supraphysiologic motion. This system included a small glenosphere that articulated with a larger intermediate polyethylene cup. Buechel et al. [7] postulated over time the muscle forces across the glenohumeral joint would lead to failure at the bone-cement or humerus-glenoid interfaces of the arthroplasty. Their early results in a small series were good, without fractures or dislocation [7].

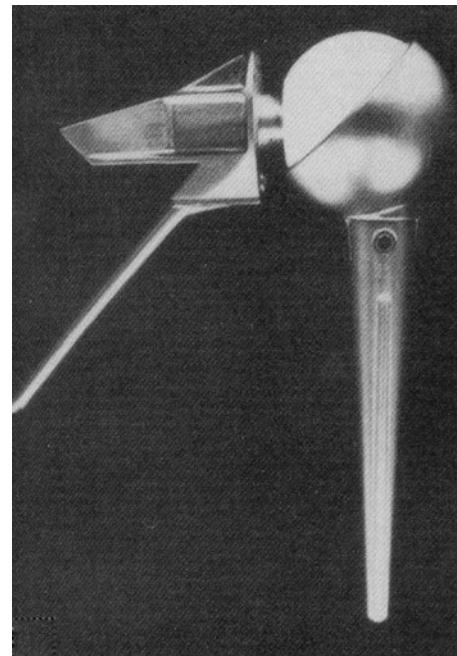


Fig. 7 The prosthesis designed by John M. Fenlin, Jr., illustrates the large glenosphere intended to maximize the deltoid function. Reprinted with permission from Fenlin JM Jr. Total glenohumeral joint replacement. *Orthop Clin North Am*. 1975;6:565–583. Copyright © 1975 Elsevier.

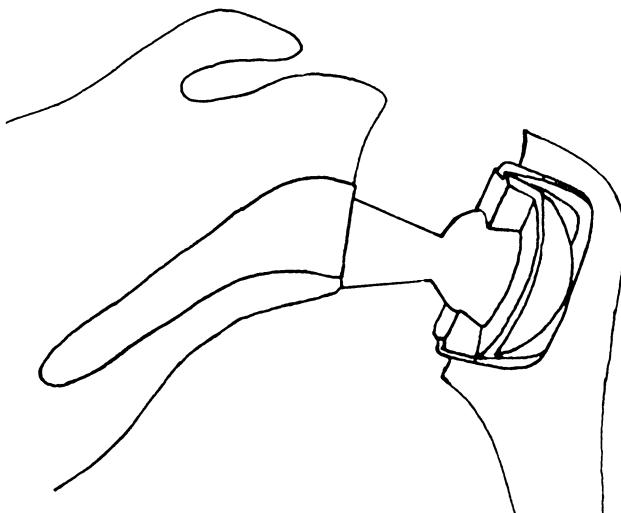


Fig. 8 In the Liverpool shoulder designed by Beddow and Elloy, the glenoid component and stem were fixed into the scapular pillar with the polyethylene socket cemented into the proximal humerus. This design recreated the anatomic center of rotation. Reprinted with kind permission of Springer Science + Business Media from Beddow FH, Elloy MA. Clinical experience with the Liverpool shoulder replacement. In: Bayley J, Kessel L, eds. *Shoulder Surgery*. Berlin, Germany: Springer-Verlag; 1982.

Similar to the Buechel prosthesis, Gristina and Webb's Trispherical system [17] from 1978 was also designed to afford a greater ROM. This system included a small sphere on the humerus and glenoid that both articulated with a central polyethylene ball in a separate metallic socket. Although this system was successful in improving pain and ROM, dislocation of the humeral sphere and glenoid component fracture marred the overall outcomes of this prosthesis.

Grammont: A New Concept

The system created by Paul Grammont in 1985 differed from previous reverse shoulder arthroplasty concepts in that Grammont's system focused on four key features [16]: (1) the prosthesis must be inherently stable; (2) the weightbearing part must be convex, and the supported part must be concave; (3) the center of the sphere must be at or within the glenoid neck; and (4) the center of rotation must be medialized and distalized. Grammont noted the deltoid function could be increased by moving the center of rotation distally and medially in comparison to the native glenohumeral articulation. Grammont et al. [16] reported on a series of eight patients with his first design. Although the center of rotation was medialized in the initial design, the center of rotation of the glenoid component remained lateral to the native glenoid surface. Grammont noted this

design allowed for increased forces at the glenoid bone-implant interface, and previous reverse shoulder arthroplasty designs too often failed due to loosening or breakage of the glenoid component. Changes in the glenoid component were made to address this concern.

In 1991, the second generation of Grammont's design (Delta III) medialized the center of rotation to the native glenoid surface by changing the glenosphere from $\frac{2}{3}$ of a sphere to $\frac{1}{2}$ a sphere. Additionally, the baseplate (metaglene) included a central press-fit peg and two divergent 3.5-mm screws designed to resist the shear forces at the bone-implant interface. The initial Delta III glenosphere screwed onto the metaglene with peripheral threads, although in some cases this mechanism unscrewed and the design was later changed to a Morse taper with a central countersunk screw.

Grammont's third variation in 1994 included changes directed primarily toward the humeral component. As surgeons gained experience and increasing numbers of the prostheses were implanted, additional options were added to address the concerns of medial impingement and instability that arose in some patients.

Discussion

Cuff tear arthropathy and the cuff-deficient shoulder present unique challenges for both the patient and orthopaedic surgeon. Early unconstrained shoulder arthroplasty systems suffered high complication and implant failure rates. The evolution toward the modern reverse shoulder arthroplasty includes many variables of constrained shoulder arthroplasty designs. This review explored the development of reverse shoulder arthroplasty, specifically describing (1) the evolution of reverse shoulder arthroplasty designs, (2) the biomechanical variations in the evolution of this arthroplasty, and (3) the current issues relevant to reverse shoulder arthroplasty today.

There are limitations inherent in this historical review. First, despite the intent to perform a cumulative review of the available literature, this may not represent an exhaustive review, particularly of the non-English literature. Second, a historical review of this subject in particular is restricted by the limited primary research published during the early decades of reverse shoulder arthroplasty. Many of the problems with the earlier designs are reported in secondary sources or other historical arthroplasty review literature.

Reverse shoulder arthroplasty now presents an option for some patients with cuff tear arthropathy and a cuff-deficient shoulder. The current indications for this prosthesis generally include patients with painful cuff tear arthropathy and pseudoparalysis, proximal humerus

fractures in the older patient with poor bone or cuff quality, tumor involving the proximal humerus requiring glenohumeral reconstruction, and revision arthroplasty in the setting of tuberosity nonunion or irreparable rotator cuff tear. Contraindications include axillary nerve deficit such that deltoid function is inadequate, active infection, inadequate glenoid bone stock to secure the glenoid component, and perhaps the younger patient. These indications and contraindications continue to be debated, such as how one defines pseudoparalysis and at what age a patient is “too young” for a reverse shoulder arthroplasty. The improved outcomes possible with this prosthesis have been well documented [18, 45, 47, 48]. The improvements in pain and ROM have therefore made reverse arthroplasty an increasingly commonly selected option for patients and subject for study.

Reverse total shoulder arthroplasty prostheses today vary in certain design details, although their intrinsic design remains based on Grammont’s principles. The variables in the current prostheses have been developed to address concerns that have arisen with reverse shoulder arthroplasty. The persistent problems and high complication rate with this procedure have been described extensively in the current literature, with complications including hematoma formation [48], infection [5, 15, 18, 45, 48, 49], scapular notching [28, 44, 45, 49], instability [18, 48, 49], acromial insufficiency [15, 48], and glenoid component failures [14, 17, 42, 45]. Additionally, complications and patient satisfaction vary among primary cuff tear arthroplasty, revision cases, and fractures [5, 15, 18, 45, 48, 49]. The followup available has demonstrated declining radiographic and clinical results after 6 to 8 years [18].

As the study of reverse shoulder arthroplasty has advanced and varying systems have developed, vibrant controversies have arisen. Debate exists over the medialization of the center of rotation, with some proposing a more lateral offset [15]. Proponents of the more lateral center of rotation point to a lower rate of scapular notching and an increase in impingement-free motion [19]. Others suggest notching may also be minimized with appropriate positioning of the more medial glenoid component [44]. These issues require additional high-quality studies and must continue to be explored and debated.

Certainly the development of the modern reverse total shoulder arthroplasty is an interesting and important aspect of orthopaedic surgery. There is much to be gained by understanding the lessons learned from the evolution of reverse shoulder arthroplasty design. Modern designs do have a high complication rate, and this procedure remains one that must be offered judiciously. Ongoing study and advancements in design are focused at addressing the challenges of this procedure. However, reverse total

shoulder arthroplasty affords improvements in pain and function for patients who previously had few, if any, options for treatment.

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